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Thermal Engineering

Elixir Thermal Engg. 65 (2013) 20050-20055

ISSN: 2229-712X

Experimental Thermal Analysis of Bend Heat pipes in Different Orientations.

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ARTICLE INFO

Article history:

Received: 10 October 2013;

Received in revised form:

2 December 2013;

Accepted: 17 December 2013;

Keywords

Test rig model,

Copper bend heat pipes,

Methanol working fluid,

Fan blower,

Manometer,

Heater,

Thermocouple,

Voltmeter and Ammeter.

ABSTRACT

Heat pipe is a device which absorbs heat from hot junction and transfer heat to other junction. If space available is more than straight heat pipes are used but when space availability is problem in electronic circuits or cards bend heat pipes are used. According to investigation it is found that bend heat pipes of angle 90 and 120 degree are most suitable in electronic systems. Experimental analysis of bend copper heat pipes for different orientations which are suitable in electronic circuits mostly are taken for study and effect of bend Angle and heat transfer rate is calculated on a test rig by using methanol as a working fluid . Study is done on bend copper Heat pipe having 8 mm diameter and length 180 mm long and find out most suitable bend heat pipe and maximum heat transfer rate.

Introduction

The concept of heat pipe was introduced in 1942 by Gaugler. Only after Grover independently invented the working of heat pipe during early 1960s it started drawing attention of researchers. Heat pipe are now in cooling of electronic components as well as temperature control.

The forerunner to heat pipe is the thermosyphon, it is cylindrical tube into which after evacuating the air a small amount of liquid is placed and sealed. When heat is applied to the liquid at the bottom (Evaporator) liquid vaporizes and vapours moves to the top. At the bottom (condenser) by cooling, the vapor is condensed and the condensate flows down along the container wall. The difference in temperature between the condenser section and the evaporator section is only about two or three degrees. Such a device has been in use for a long time [1]

The basis of using micro-fibrous metal felt wicks in heat pipes is based upon Williams and Harris (2003), Williams and Harris (2005) and Odhekara (2005), this class of heat pipe can be bent into conformal shapes after fabrication and sealing. E.g. straight heat pipes of this variety can be acquired and integrated into systems requiring bended shapes in order to fit into contorted geometries.

Background of Flexible heat pipes- A flexible heat pipes was developed and built by Blissetal,(1970) to analyze its operating characteristics for varying degrees of bend and under vibration in an unbend mode. The purpose of this study was to design a flexible heat pipes capable of being bent or flexed during its operation allowing efficient heat transfer between an oscillating heat source and a stationary sink. The heat pipes used methanol as the working fluid and tests were conducted.

Bendable wicks.-only certain wicks can be used in bendable heat pipes. And wick will have a tendency to separate from the container walls under bending. This separation has two adverse effects, a reduction in the vapor core area that reduces heat transfer capacity and a disruption in the path of liquid flowing back to the evaporator. The sintered copper felt wick provides a very flexible wick material that does not crack after bending as well. However, a wick made from sintered metal powder will crack under bending. Lastly it was found that deformation of bend heat pipe is acceptable only in adiabatic section and not in the condenser section and evaporator section. [2]

Working fluid:

Using the proper working fluid for a given application is another critical element of proper heat pipe operation. The working fluid must have good thermal stability properties at the specified operational temperature and pressure. The operational temperature range of the working fluid has to lie between its triple point and its critical point for liquid to exist in the wicking material. The wet ability of the working fluid contributes to its capillary pumping and priming capability. Vaporization, low liquid viscosity, and a low vapor viscosity are necessary.

Heat pipe classification by working fluid:

Theoretically, heat pipe operation is possible at any temperature between the triple state and the critical point of the working fluid utilized. Several typical heat pipe working fluids are given in Table 1, along with the corresponding triple point, critical point, and most widely utilized temperature range for each individual fluid. Classification of heat pipes may be in terms of geometry, intended applications, or the type of working fluid utilized. Each heat pipe application has a temperature range in which the heat pipe is intended to operate. Therefore, the working fluid must be chosen to take into account this operating temperature (along with the Pressure condition), but also its chemical compatibility with the container and wick materials. Depending on operating temperature, four different types of heat pipes are usually described with regard to commonly used working fluids: [3]

Effect of Fluid Charge:

(1) **Low fill ratio**: When the heat input is given, the fluid at the evaporator section is vaporized at a faster rate and due to the accumulation of more vapor at the condenser section, it leads to

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dry out phenomenon at the evaporator section, hence condensation occurs at a lower rate.

Medium	Boiling Point ◦C	Useful Range ◦C
Helium	-261	-271 to -269
Nitrogen	-196	-203 to -160
Ammonia	-33	-60 to 100
Pentane	28	-20 to 120
Acetone	57	0 to 120
Ethanol	78	0 to 130
Heptanes	98	0 to 150
Methanol	64	10 to 130
Flutec PP2	76	10 to 160
Water	100	30 to 200
Toluene	110	50 to 200
Thermax	257	150 to 350
Mercury	361	250 to 650
Caesium	670	450 to 900
Potassium	774	500 to 1000
Sodium	892	600 to 1200
Lithium	1340	1000 to 1800
Silver	2212	1800 to 2300

Table-1: Working Of Fluid Temperature Range

2) **High fill ratio**: The evaporator section temperature is lower and hence evaporation occurs at a lower rate. This results in very little vapour flowing into the condenser section, At 100% filled ratio, heat pipe operates like a single phase thermo- siphon with action maximum for a vertical heat pipe and stops for a horizontal heat pipe. The heat transfer takes place purely by axial conduction in a horizontal heat pipe. A number of experiments have been performed using varying heat inputs and filled ratios. Experiments were carried out in dry mode ([4]

Forced convection:

When natural convection cooling is not ad equate, forced convection is provided by external means such as a fan, a pump, a jet of air, etc. In electronic systems cooling, fan is a popular Means of circulating air over hot surfaces. For forced convection the hot surfaces are characterized by their ex tended surfaces such as fins in heat sinks. The use of micro jet of air to cool hot pots is more attractive. The fan selection is the important aspect in forced convection. The following are the two primary considerations in the selection of the fan: The static pressure head of the system, which is total resistance, an electronic system offer to air as it passes through, and – the volume flow rate of air required for cooling

Enhancement with heat sinks:

It increases the effective surface area for heat transfer and lower thermal resistance between source and sink. Heat sinks can be operated under free or forced convective modes depending on the cooling load requirement. Due to their inherent simplicity, reliability and low long term costs, natural convection heat sinks have proven to be instrumental in cooling single or multiple chip circuit boards. The geometries encountered in heat sink assemblies are difficult to model using analytical techniques because of the complex fluid flow around and between the various components of the heat sink. [5]

Heat pipes are very efficient heat transport elements. They can be described as light weight devices with high thermal conductance. Heat pipes allow the transportation of high fluxes with small temperature difference with no change in the operating temperature. At zero-gravity environment and against gravity heat pipes can operate. In addition, there is no moving mechanical part in heat pipes, and special sets of them can be used for temperature control, as thermal diodes and thermal switches. Also, they can be built in difference geometries and sizes. [6]

The heat pipe is a thermal device which affords efficient transport of thermal energy by using an intermediate heat transfer fluid. By suitable design, heat pipes are being constructed to serve diverse functions such as precise temperature control, one-way transmission of heat (thermal diode) and heat flux amplification and diminution. [The heat pipes are more advantageous in heat recovery systems, solar energy, Electronics cooling, Ocean thermal energy conversion, air craft cooling, Geothermal conversion and light water nuclear reactors. The common sections of the vapour space are circular, rectangular and annular and are chosen based on the application of heat pipe. [7]

Experimental set up:

Trial procedure:

The trial is conducted on the heat pipe system to determine the temperature difference at ambient temp. And duct air temp. At sink.. Procedure is as follows:

Copper Heat pipe system with fin – bend angle-70, 90 and 120 degree.

1. Started power supply to heater, and achieved steady state.
2. Started circulation of air by blower to condensation jacket side at lower speed.
3. Taken temperature readings at ambient temp and duct temp of air at sink .calculated different air flow rate readings at different speed.
4. Temperature readings are taken for different set of air flow conditions.

Experimental analysis:

1. Design and development of test-rig
2. Testing of various heat pipes to derive the following results

a) Heat transfer coefficient (h), $w/m^{2-}K$

b) Heat transfer ability

c) Heat dissipation ability of device (watt)

3. To carry out comparative study of experimental and experimental analysis results to decide the optimization of angle of bend, and effectiveness of heat pipe system at various angles.
4. The system will designed for the following orientations:

a) Acute angle bend (70 degree bend)

b) Right angle bend (90 degree bend)]

c) Obtuse angle bend (120 degree bend)

The set-up of the heat pipe will comprise of the following parts:

a) Heat Pipe: The heat pipe is copper heat pipe, with following specifications:

1. Material of pipe: Copper. 2. Wick structure: Porous Sintered. 3. Material of wick: Sintered copper. 4. Working Fluid: Methanol (35-40 percentages). 5. Size: 8 mm diameter. 6. Length: 180 mm. 7. Adiabatic length-60mm. 8. Condensing lenth-60mm. 9. Evaporator length-60mm

b) Source Block; Source block is a cylindrical aluminum block that receive the evaporator end of heat pipe in the inside where as the band heater on its outside.

b) Sink block : Sink block is an cylindrical aluminum block that receive the condenser end of heat pipe in the inside where as the outside of the block are provided with cylindrical radial fins with view to increase surface area available for heat transfer , so also allow maximum air flow over body.

c) Band heater is mounted on the source block with 85 to 100 watt capacity, 230 Volt AC.

Details of heat pipe structures:

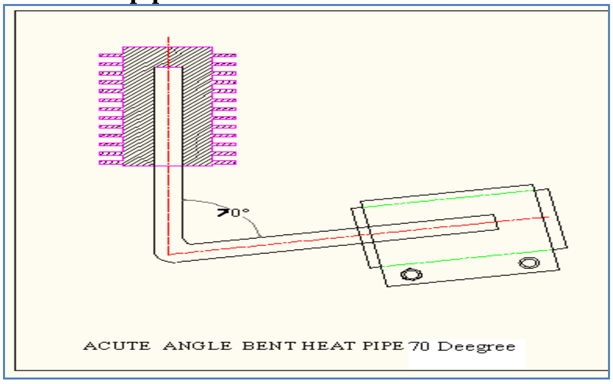


Figure1: Heat pipe- 70ºangle of bend

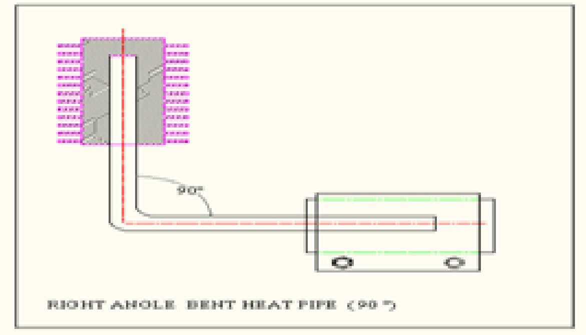


Figure2: Heat pipe: 90ºangle of bend

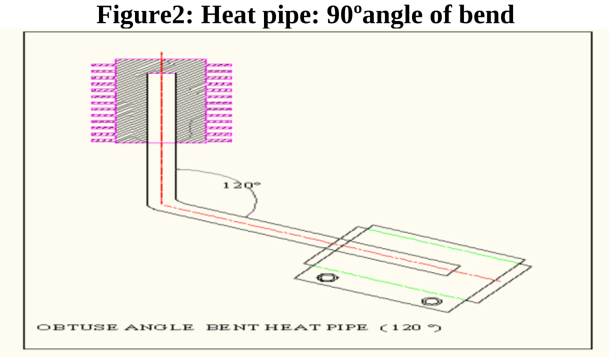


Figure 3: Heat pipe: 120º angle of bend.

Figure 4: Heater-85watt.

Figure 5: Actual Test rig

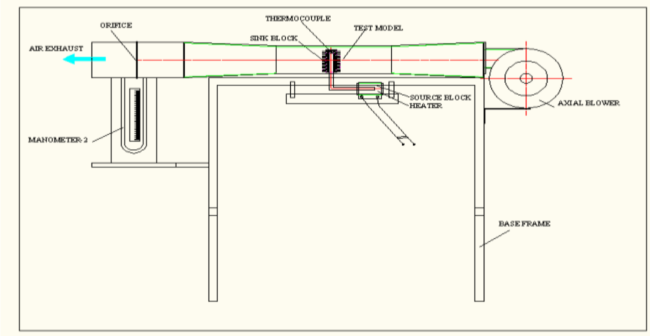


Figure No. 6 Test Rig (Wind Tunnel Type)

Figure 7: Circular aluminium fin.

Figure 8: Blower fan.

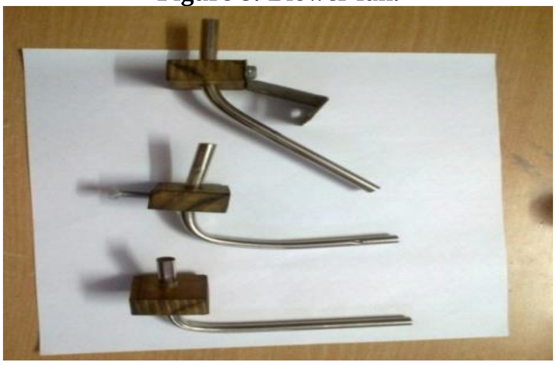


Figure 9: Heat pipe with actual bends-70º, 90º, and 120 º

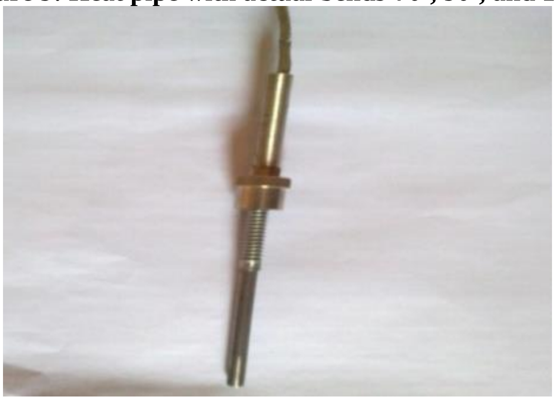


Figure 10 J-type Thermocouple

Test procedure:

The test is conducted on the heat pipe system as below.

i. Start power supply to heater, until steady state is achieved.

ii. Start the blower and maintain speed at Level-1

iii. Take manometer reading (H) mm of water. Using this reading it is possible to find velocity of air and discharge at Level-1 of speed of blower.

iv. Take temperature readings at inlet (ambient temperature) and outlet also readings for air flow rate.

v. Temperature readings are taken for different set of air flow conditions.

vi. Measure voltage, current using Voltmeter, Ammeter respectively.

a. Measure voltage (Volts) using voltmeter

b. Measure current (amps) using Ammeter

vii. Note down thermocouple temperature reading (T_f) and temperature gradient

$(\Delta T) = (T_f - T_a)$

viii. Repeat the same set of reading for different levels of manometer readings i.e. Level-2. Level-3. Level-4, level-5 and level-6.

Working Formulae:

1. Discharge:

$$Q = Cd \times a\sqrt{2gH} \quad m^3/sec$$

2. $Q = a \times v$
3. $v = Q/a$
4. $R_e = \rho \times v \times l / \mu$
5. $\upsilon = \mu / \rho$
6. $R_e = v \times l / \upsilon$
7. $q = h A (\Delta T)$.
8. $N_u = 0.64 \, Re^{1/2} (\mu C_p/K)^{1/3}$ –For Laminar Flow.
9. $N_u = hl/k$
10. $P_r = \mu C_p/K$
11. $h = 0.64 \, Re^{1/2} (\mu C_p/K)^{1/3} (K/l)$
12. Effectiveness of fin = Heat output / Heat input
13. . Heat input = wattage x correction factor
14. Length of Fin (l) = π x D_F x No. of fin surfaces
15. Area of Fin (A) $= 2\pi (R^2_{2C} - R_1^2)$
16. Total Area of Fin = Area of one Fin x No. of Fins.

where $R_{2C} = R_2 + t/2$, $R_2 = R_1 + l$

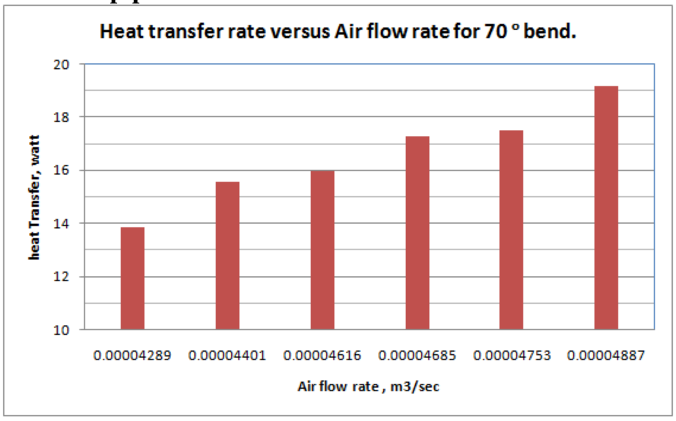
Observations:

1. Diameter of Orifice(d) = 16.5 mm
2. Area of Orifice (a) $m^2 = (\pi/4) \times d^2$
3. Coefficient of discharge $(C_d) = 0.6$
4. Velocity of air (v) in m/s
5. Heat transfer (q) in watt.
6. Heat transfer coefficient (h) in w/m^2-k
7. Area of Fin A= 0.37 m^2.
8. Length of Fin (l) in m.
9. At temp. 30° of air following properties are found.

υ= kinematic viscosity of air = 16 x 10^{-6} m^2/sec, Pr = 0.701, ρ = density of air = (1.165 kg/m^3), C_p = specific heat of air = 1005 J/kg-k, K=0.02675 W/m-k, μ-= 18.65x 10^{-6} kg/m-sec

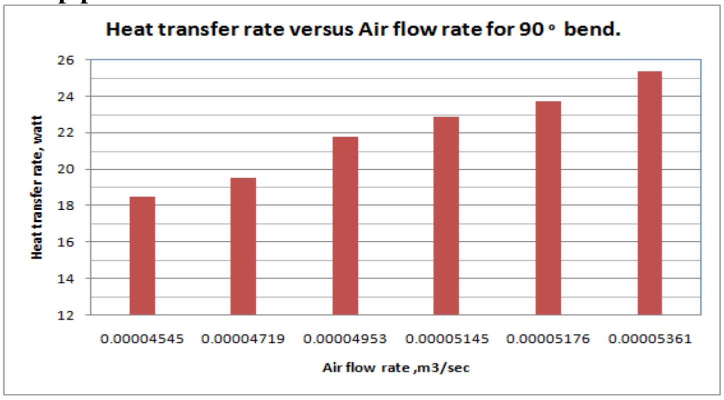
10. Duct air Temperature and Ambient Temperature in degree centigrade.
11. Discharge (Q) in m^3/sec.
12. Kinematic viscosity of air (υ) in m^2/sec
13. Dynamic viscosity of air (μ) in kg/m-s
14. Specific heat of air (C_p) in J/kg-k
15. Density of air (ρ) in kg/m^3
16. Thermal conductivity (k) in w/m-k

Actual Measurements of Different Parameters for 70° angle bend heat pipe.



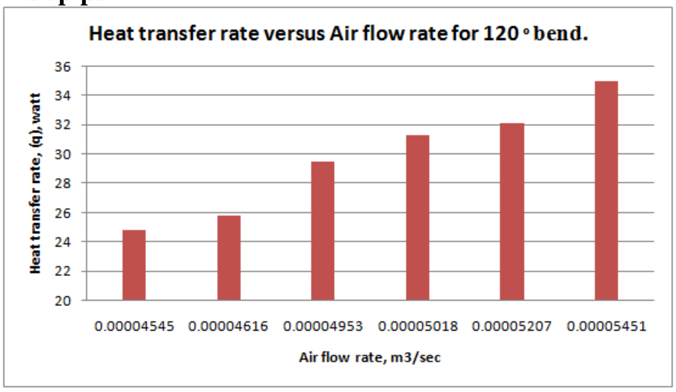
Graph.No.1: Heat transfer in watt versus air flow for 70 degree bend.

Measurements of Different Parameters for 90° angle bend heat pipe



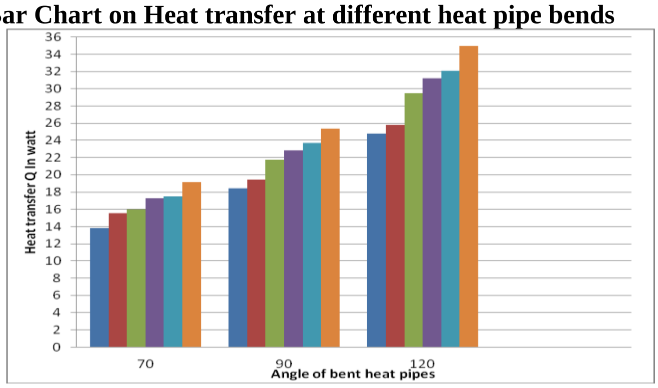
Graph.No.2 Heat transfer in watt versus air flow for 90 degree bend.

Measurements of Different Parameters for 120° angle bend heat pipe



Graph.No.3 Heat transfer in watt versus air flow for 90 degree bend

Bar Chart on Heat transfer at different heat pipe bends



Graph No.4 Bar chart on bent heat pipes

Observation table-1

Sr.No	Voltage (Volt) V_0	Time T (Min)	Current (Amps)	Manometer Reading (H),(cm)	Duct Air Temp. T_f ^{0} C	Ambient Temp. T_a ^{0} C	ΔT
Level-1	220	5	0.39	0.57	51	29	22
Level-2	225	5	0.40	0.60	52.4	28	24.4
Level-3	224	5	0.41	0.66	53.5	29	24.5
Level-4	226	5	0.42	0.68	54.2	28	26.2
Level-5	221	5	0.42	0.70	55.4	29	26.4
Level-6	220	5	0.43	0.74	56.5	28	28.5

Observation Table-2

Sr.No.	Discharge (Q) m^3/sec	Velocity (v) m/s	Re (Reynolds number value)	Heat transfer coefficient. (h) in w/m^2 k	Heat transfer by heat pipe (q) in (watt.)	Effectiveness (ε)
1	0.00004289	0.200	12500	1.70	13.83	0.230
2	0.00004401	0.205	12812	1.72	15.55	0.259
3	0.00004616	0.215	13493	1.76	15.99	0.266
4	0.00004685	0.219	13695	1.78	17.26	0.287
5	0.00004753	0.222	13875	1.79	17.51	0.291
6	0.00004887	0.228	14250	1.81	19.15	0.319

Observation table-3

Sr. No.	voltage (volt) V_0	Time T (Min)	Current (amps)	Manometer reading (H) (cm)	Duct air temp. T_f ^{0}C	Ambient Temp. T_a ^{0} C	ΔT
Level-1	220	5	0.40	0.64	56.5	28	28.5
Level-2	225	5	0.42	0.69	57.5	28	29.5
Level-3	224	5	0.41	0.76	60.3	28	32.3
Level-4	226	5	0.42	0.82	62.2	29	33.2
Level-5	221	5	0.40	0.83	63.5	29	34.5
Level-6	220	5	0.40	0.89	64.0	28	36

Observation table-4

Sr.No.	Discharge (Q) m^3/sec	Velocity (v) m/s	Re (Reynolds number value)	Heat transfer coefficient(h) in w/m^2 k	Heat transfer by heat pipe (q) in watt.	Effectiveness (ε)
1	0.00004545	0.212	13250	1.75	18.47	0.307
2	0.00004719	0.220	13750	1.78	19.42	0.323
3	0.00004953	0.231	14437	1.82	21.75	0.362
4	0.00005145	0.240	15000	1.86	22.84	0.380
5	0.00005176	0.242	15125	1.86	23.74	0.395
6	0.00005361	0.250	15625	1.90	25.37	0.422

Observation Table-5

Sr.No	voltage (volt) V_0	Time T (min)	current (amps)	Manometer reading (H) (cm)	Duct air temp. T_f ^{0} C	Ambient Temp. T_a ^{0} C	ΔT
level-1	220	5	0.40	0.64	66.3	28	38.3
level-2	225	5	0.40	0.66	67.4	28	39.4
level-3	224	5	0.42	0.76	72.5	29	43.5
level-4	226	5	0.43	0.78	73.8	28	45.8
level-5	221	5	0.43	0.84	75.4	29	46.4
level-6	220	5	0.44	0.92	77.3	28	49.3

Observation Table-6

Sr.No.	Discharge (Q) m^3/sec	Velocity (v) m/s	Re (Reynolds number value)	Heat transfer coefficient (h) in w/m^2 k	Heat transfer by heat pipe (q) in watt.	Effectiveness (ε)
1	0.00004545	0.212	13250	1.75	24.79	0.413
2	0.00004616	0.215	13494	1.76	25.77	0.429
3	0.00004953	0.231	14438	1.83	29.45	0.490
4	0.00005018	0.234	14669	1.84	31.25	0.520
5	0.00005207	0.243	15187	1.87	32.10	0.535
6	0.00005451	0.254	15875	1.92	35.00	0.583

Conclusion:

Heat pipe is a device which absorbs heat from hot junction and transfer heat to other junction. If space available is sufficient then straight heat pipes are used but when space availability is problem as in electronic circuits or cards bent heat pipes are used. According to investigation it is found that bent heat pipes at angle 120 degree is most suitable in electronic systems.

By using bent copper heat pipe with 180 mm length and 8mm diameter at different inclination angles heat transfer rates at different levels are calculated.

Bent copper heat pipes having different angles 70º, 90º and 120º are used and the heat transfer rates and effectiveness are calculated.

By using methanol fluid heat transfer rate of 90 º angle bent heat pipes is more than 70º angle heat pipe. By using same fluid it is found that heat transfer rate of 120º angle bent is more than 90º angle bent heat pipe.

Thus bent heat pipe at 90^0 is 1.32 times effective than bent heat pipe at 70^0.and bent heat pipe at 120^0 is 1.38 times effective than bent heat pipe at 90^0. Thus bent heat pipe at 120^0 is 1.8 times effective than bent heat pipe at 70^0.Hence bent heat pipe at 120^o is recommended

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